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ADVANCED ALUMINUM ALLOYS
FROM
RAPIDLY SOLIDIFIED POWDERS.

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ADVANCED ALUMINUM ALLOYS FROM RAPIDLY SOLIDIFIED POWDERS

Advanced aluminum alloys are to be developed that will provide major payoffs for important new aircraft, spacecraft, and missile systems in the next decade. Payoffs will result from weight savings of structural components which, in turn, lead to increased range, payload, service life, and decreased life-cycle cost. Recently conducted feasibility and design tradeoff studies provide a basis for selecting certain property goals for improved aluminum alloys that will result in significant weight savings. These property goals are:

- A. Specific Elastic Modulus — 133×10^6 in.
- B. Specific Elastic Modulus — 122×10^6 in., and
Specific Yield Strength — 7.96×10^5 in.

Goal A is a 30-percent increase in specific modulus of elasticity relative to Al 7075-T76, without significant loss in strength, toughness, fatigue strength, or stress-corrosion resistance. Goal B is a 20-percent increase in specific modulus of elasticity accompanied by a 20-percent increase in specific strength, without significant loss in toughness, fatigue strength, or stress corrosion resistance.

1.0 OBJECTIVE

The objective of this program is to develop advanced aluminum alloys from rapidly solidified particulate that meet specific property goals. In addition, the program is to establish a metallurgical basis suitable for manufacturing scale-up and application to new weapon systems.

2.0 SCOPE

The program is divided into three phases, each consisting of a number of tasks. Phase 1 involves fundamental alloy development studies and consolidation

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process development and optimization. The most promising alloys are to be selected, produced in simple mill form, and evaluated in Phase 2. Phase 3 will consist of a design evaluation using the properties of the alloys evaluated in Phase 2.

This program was initiated in September 1978 and is scheduled for completion in 3-1/2 years. The effort during the first two years will be devoted to Phase 1 only. This report describes activity during the reporting period in each of the four tasks comprising Phase 1.

3.0 PROGRESS

3.1 Task 1 - Development of Alloys Containing Lithium

This task is being performed by LMSC with Dr. I. G. Palmer as principal investigator.

Characterization of Heat Treated Alloys

A set of extrusions was prepared having different aspect (width/thickness) ratios, using alloy 1.2 (Al-3Li-2Cu-0.2Zr). Tensile data was obtained for the peak aged condition, [463K (375°F) for 8 h] and is shown in Figures 1 and 2. Yield strength values were found to range from 521 MPa (75.6 ksi) for round axisymmetric extrusions to 414 MPa (60.0 ksi) for sheet bar extrusions of aspect ratio 8:1. This is a significant effect and is attributed to differences in crystallographic texture; texture measurements are being made to correlate with the tensile data. The yield strengths showed the usual inverse correlation with tensile elongation (Fig. 1), and there was no significant improvement in the combination of strength and ductility for any extrusion condition. The greatest change in yield strength occurred for aspect ratios between 1 and 2 (Fig. 2), therefore in order to avoid this enhancement in yield strength, aspect ratios of greater than 2 should be used.

The effect of other processing conditions on tensile properties has been evaluated using alloy 1.2 including the addition of multiaxial ABC forging

prior to extrusion, use of chopped up splat, use of a single screen fraction (-8/+16) splat to minimize presence of nonsplat particles, variations in solution treatment time and temperature, extrusion die design (shear die versus 90 degree entrance angle), and extrusion temperature. The results are shown in Table 1, and are average values of two tests. The most significant improvement resulted from the use of multiaxial ABC forging of the hot pressed billet prior to extrusion. The tensile data shown in the Table (yield strength 64.6 ksi, 446 MPa and elongation 5.2%) represents an average from two specimens, one of which showed the best combination of yield strength (64.6 ksi, 446 MPa) and elongation 6.2%), so far observed. Evaluation of this processing method will therefore be continued. The improvement in ductility is attributed to improved break-up of oxide films on prior particle boundaries.

Use of higher solution treatment temperatures gave higher yield strength values as a result of an increase in the amount of solute taken into solution and subsequently precipitated. No systematic trend in elongation values was observed, probably as a result of scatter in the experimental data.

Second Iteration Alloys

Alloy compositions have been selected so that the Li, Cu and Mg alloying elements are fully solutionizable. This assumes that the alloys will be consolidated by conventional means, and will require heat treatment after consolidation. Previous work on first iteration alloys 1.1 and 1.2 showed that the presence of brittle insoluble constituent particles resulted in lower ductility. The alloy compositions are shown in Table 2.

Alloys 1.9 and 1.10 are designed to meet the goal A specific modulus and are modifications of the best first iteration alloy, 1.2. The Cu level has been decreased to 1.5 wt. % and 1 wt. % of Mg has been added. The intention is to compare this alloy composition in two forms, with and without a dispersoid.

Alloys 1.11 and 1.12 are designed to meet goal B specific modulus and specific strength and contain 2 wt. % Li. The intention is to compare the composition in two forms with and without the Zr grain refiner.

Novel Consolidation Techniques

A small lot of splat alloy 1.1 (Al-4Cu-3Li-0.2Zr) was sent to CERAC for their dynamic consolidation trials.

3.2 Task 2 - Development of Non-Lithium-Containing Alloys

This task is being conducted by the Alcoa Laboratories, with Dr. H. G. Paris and Mr. F. R. Billman as principal investigators.

First Alloy Iteration Property Screen

In this Quarter, all first iteration alloys were fabricated and tested. Several alloys produced E/ρ values between that of goal B and goal A, while alloy 2.8A (Al-14Mn) exceeds E/ρ for goal A. Alloy 2.6A (Al-10Mn-2.5Si) exhibited high tensile ductility at strengths of ~ 310 MPa (45 ksi) suggesting that higher solute contents are feasible in these alloys. The alloys based on Al-Fe-Ni-Co (alloys 2.1A-2.4A) all show promise of approaching goal B by improving their strength.

Alloys produced in splat particulate form exhibit a wider variation in microstructure than do the same alloys in powder form. This results in lower strengths. Splats produced by generation in an argon atmosphere are of even lower strength due to limitations in control of process parameters in splat production using argon. This results because the molten metal droplets are larger using argon and the residence time on the drum is relatively constant, thus less heat can be extracted by conduction relative to that extracted from smaller droplets produced in air generation.

A significant observation has been made in the microstructural studies at Carnegie-Mellon University. Even at the moderate strength and high ductility levels of ~ 310 MPa (45 ksi) and $\sim 15\%$ elongation produced in alloy 2.6A, the fracture mechanisms appear to be limited not by matrix plasticity but by the interparticulate oxides. This observation is important because it implies that control of the oxide character, especially at high strength levels, may enhance the alloy ductility.

Second Alloy Iteration Property Screen

The selection of alloys for the second iteration of compositions has been accomplished. The Al-Mn system is selected for alloy properties satisfying contract goal A. These alloys are ductility limited, therefore an argon atmosphere will be used to control oxidation in atomizing. Since fine atomized powder particulate results in better strength than splat, it will be the primary one used. The Al-Fe-Ni-Co and Al-Mn-Si systems are selected to produce properties approaching contract goal B, where a further improvement in strength, not specific modulus, is needed. Two splat particulate controls are to be used in the Al-Mn-Si alloys and in the Al-Fe-Ni-Co alloys.

3.3 Task 3 - Quantitative Microstructural Analysis and Mechanical Property Correlations

This task is being conducted by Georgia Institute of Technology with Dr. E. A. Starke, Jr. as principal investigator.

Fracture Surface Studies of Tensile Specimens Made from Fine Atomized Powder

Fractured tensile specimens of Al-Li-Ni-Fe alloys with about 3.5 wt.% Li and different concentrations of Ni and Fe have been obtained from LPARL to study the fracture mechanism. These alloys were made from fine atomized powders, supplied by Homogeneous Metals, and processed in the same way as the splat quenched alloys. The elongation to fracture values for under-, peak-, and over-aged microstructures ranged from about 3 to 5.7% for the four different alloys. The fracture surfaces of alloy H2 (Al-3.5Li-1.1Ni-1.0Fe) in the under-, peak-, and over-aged condition have been studied in more detail. It was found that crack initiation occurred at large inclusions in all three specimens. At low magnification the SEM micrographs clearly showed a river pattern originating at these inclusions. The diameters of these spherical particles ranged from about 30 to 80 μm . X-ray energy spectrometer measurements revealed high concentrations of Ni, Co, and Al within three particles with additional smaller amounts of Cr and Fe. Similar particles also have been observed at Georgia Institute of Technology in P/M 2020 alloys made from fine atomized powder provided by Homogeneous Metals. The large size of these

particles and a relatively weak interface bonding between particle and matrix seem to be responsible for early crack initiation in these alloys.

Effect of TMT on Yield Stress of Alloy 1.2 (Al-3Li-2Cu-0.2Zr)

Earlier, TEM studies of alloy 1.2 have shown that the distribution of θ' -precipitates upon aging is rather inhomogeneous. In the underaged condition θ' precipitated mainly at dislocations and the volume fraction was very low, while in the peak- and over-aged condition the θ' -precipitates were coarse and therefore did not contribute in an effective way to increase the yield stress. An attempt was made to obtain a more homogeneous distribution of finer particles by applying TMT procedures. A rolling deformation of about 14% after quenching from the solution heat treatment temperature did not improve the yield stress significantly upon aging.

However, stretching in tension proved to be a more effective TMT procedure. As-extruded bars were solution heat treated, quenched and stretched 2% plastically in tension. After 2 days of RT aging blanks for tensile specimens were aged at 463K (375°F) for 0.75 h (underaged) and 8 h (peak-aged). The tensile tests resulted in yield stress values of 518 MPa (75 ksi) for the underaged condition and 582 MPa (84 ksi) for the peak-aged condition. For comparison the values without stretching obtained for alloy 1.2 were about 460 MPa (67 ksi) and 500 MPa (72.5 ksi) for the under- and peak-aged condition respectively. The plastic elongation to fracture for the stretched and aged material was about 3.5% in the under-aged and 3% in the peak-aged condition. TEM studies showed that in the stretched and aged material the distribution of θ' -precipitates was more homogeneous and the size was much smaller in comparison to the unstretched condition.

Compression Tests

Cylindrical specimens (6 mm diameter, 9 mm length) of alloy 1.2 in the peak-aged condition were deformed in compression to study the deformation behavior. Some of these specimens fractured after about 10% plastic deformation by shear failure, while one specimen was deformed about 16% without fracture. The stress-strain curves of specimens which fractured showed several load

drops (pop-ins) shortly before failure. Some compression tests on additional specimens were therefore interrupted before final fracture after a few load drops had been observed on the stress-strain curves. These specimens were cut parallel to the loading axis, polished and slightly etched to study the crack path by light and scanning electron microscopy. The cracks were observed to consist of two different types: rather straight portions and in between these cracks smaller ones which were not connected directly with each other and which appeared under a different angle as compared to the straight cracks.

At lower compressive plastic deformations (1.3%) some indications of slip band formation have been observed within grains or subgrains. However TEM foils of a specimen deformed 16% in compression did not show shear offsets at grain or subgrain boundaries. Preferred thinning was observed at grain boundary triple points in these highly deformed specimens.

3.4 Task 4 - Application Studies

This task is being performed by Lockheed-California Company under the direction of R. F. Simenz.

There were no activities on this task in the report period. However, during the remaining Phase 1 period, the following will be conducted.

- (a) The weight savings prediction model will be finalized. This will include combining tensile strength and compression strength into one category, since analysis has shown that the weight of structure critical for the first power of the compression strength is small. Minimum gage structure and general instability failure mode categories will be added. The minimum gage category will account for structure which must meet serviceability, handling, foreign object damage, or lightning attenuation requirements. General instability is proposed as an additional category because much of the weight of fuselage shell frames and wing structural box ribs are determined by this failure mode.

(b) Material property data generated on lithium and non-lithium containing aluminum alloys showing the best combination of properties will be analyzed for various structural applications in both a S-3 patrol and ATF aircraft. Weight savings will be determined and the impact of variation from goals will be assessed and recommendations made for Phase II alloys and properties.

(c) Structural applications showing payoffs in item b above will be reviewed to make a preliminary determination of processing requirements and possible manufacturing limitations associated with the particular alloys being studied.

4.0 MAJOR ITEMS OF EXPERIMENTAL OR SPECIAL EQUIPMENT PURCHASED OR CONSTRUCTED DURING THE REPORTING PERIOD

None.

5.0 CHANGE IN KEY PERSONNEL DURING THE REPORTING PERIOD

None.

6.0 NOTEWORTHY TRIPS, MEETINGS, ETC. DURING THE REPORTING PERIOD

On May 22, 1980 at Stone Mt., GA, a contract review was held with Dr. L. R. Bidwell, Air Force Materials Laboratory, Program Manager. The main item discussed for new consideration was the value of extending the time table for Phase 1 from a total of 24 to 27 months, thus allowing for completion of third iteration Al-Li alloys and addition of a third alloy iteration at the Alcoa Laboratories. This extension was unanimously recommended by the team members, and L. R. Bidwell and R. E. Lewis agreed to undertake action to set up such a modification.

In April 1980, I. G. Palmer visited several research establishments in the UK working on rapidly solidified aluminum alloys and on aluminum-lithium alloy development. Most of the work in rapid solidification is being performed at the Universities (Cambridge, Sheffield, Sussex, Swansea) sponsored

mainly by the Science Research Council and the Ministry of Defence, with smaller efforts in the Laboratories of British Aluminium, Tube Investments and ALCAN. Work is being performed on both microcrystalline and amorphous alloys. Activity on aluminum-lithium alloys is going on at The Royal Aircraft Establishment, British Aluminium and Nottingham University, all under Ministry of Defence sponsorship. The aim of the work is to develop ingot-cast alloys for aerospace structural applications. The work is intended to develop the optimum compositions in aluminum-lithium-magnesium based alloys. Also, British Aluminium is working to solve the various problems associated with casting and rolling of aluminum-lithium alloys on a commercial scale.

Three papers based on contract activities were presented at the Second International Conference on Rapid Solidification Processing and Technology, held at Reston, Va., March 23-26, 1980.

1. T. H. Sanders, Jr., J. W. Johnson, and E. E. Underwood, "Microstructural Analysis of Wrought RSP Al-Fe-Ni-Co Alloys."
2. F. R. Billman, H. G. Paris and J. I. Petit, "The Influence of Particulate Morphology and Thermal History in Consolidation and Metal Working on Mechanical Properties of Al-Fe-Ni-Co and Al-Mn-Si Alloys."
3. I. G. Palmer, R. E. Lewis, and D. D. Crooks, "Low Density, High Modulus Aluminum-Lithium Alloys from Splat Particulate."

Two papers based on contract activities were presented at the First International Conference on Aluminum-Lithium Alloys, held at Stone Mt., GA, May 19-21, 1980.

1. I. G. Palmer, R. E. Lewis, and D. D. Crooks, "The Design and Mechanical Properties of Rapidly Solidified Al-Li-X Alloys."
2. A. Gysler, R. Crooks and E. A. Starke, "A Comparison of Microstructure and Tensile Properties of P/M and I/M Al-Li-X Alloys."

7.0 SUMMARY OF PROBLEMS OR AREAS OF CONCERN IN WHICH GOVERNMENT ASSISTANCE OR GUIDANCE IS REQUIRED

None.

8.0 ANTICIPATED DEVIATION IN PLANNED EFFORT TO ACHIEVE CONTRACT OBJECTIVES

Note proposed extension for completion of Phase 1, described in paragraph 6 above.

9.0 FISCAL STATUS

9.1 Amount Currently Provided for Contract Program

\$714,210 through Mod 1 of Contract (through FY80), of which \$696,691 is for Phase 1, and balance is to be applied towards Phases 2 and 3.

9.2 Expenditures and Commitments to Date (6-5-80)

\$696,691 including fee.

Including unliquidated commitments of:

\$ 1,928	Perkin Elmer
11,959	Lockheed-California Co. ITA
27,273	ALCOA Purchased Service for RSP
48,432	ALCOA Sub-Contract
4,346	Georgia Tech Sub-Contract
185	Materials
<u>3,149</u>	Procurement Burdens
\$ 97,270	Sub-Total
<u>7,402</u>	Fee
\$104,672	Total Procurement Commitments

9.3 Estimated Date of Work Completion

Phase 1 - September 4, 1980 (current plan); December 4, 1980 (revised date with proposed extension)

Total Contract - June 5, 1982.

Table 1

EFFECT OF PROCESSING CONDITIONS ON TENSILE PROPERTIES
OF ALLOY 1.2 (Al-3Li-2Cu-0.2Zr), SOLUTION TREATED AT 811K (1000°F)
AND AGED AT 463K (375°F) EXCEPT WHERE INDICATED

Extrusion #	Processing Condition	0.2% Yield Strength MPa (ksi)	Tensile Strength MPa (ksi)	Elongation (%)
1.2A-6	Solution Treated at 833K(1040°F)	453 (65.7)	550 (79.8)	3.8
1.2A-3	Solution Treated at 811K(1000°F)	446 (64.6)	516 (74.9)	3.0
1.2A-6	Solution Treated at 783K(950°F)	439 (63.6)	508 (73.6)	5.4
1.2A-6	Solution Treated at 755K(900°F)	427 (61.9)	478 (69.3)	4.1
1.2A-7	Extruded at 789K(960°F)	448 (65.0)	538 (78.1)	3.1
1.2A-8	Multiaxial ABC Forged	446 (64.6)	531 (77.0)	5.2
1.2A-9	Single Screen Fraction (-8/+16)	457 (66.2)	527 (76.5)	2.5
1.2A-14	Splat Chopped to -50 Mesh	445 (64.5)	527 (76.4)	3.7

Table 2

COMPOSITIONS FOR SECOND ITERATION Al-Li Alloys

LMSC Alloy No.	Composition (wt %)					
	<u>Li</u>	<u>Cu</u>	<u>Mg</u>	<u>Fe</u>	<u>Ni</u>	<u>Zr</u>
1.9	2.8	1.5	1.0	-	-	-
1.10	2.8	1.5	1.0	0.5	0.5	-
1.11	2.0	3.0	1.0	-	-	-
1.12	2.0	3.0	1.0	-	-	0.2

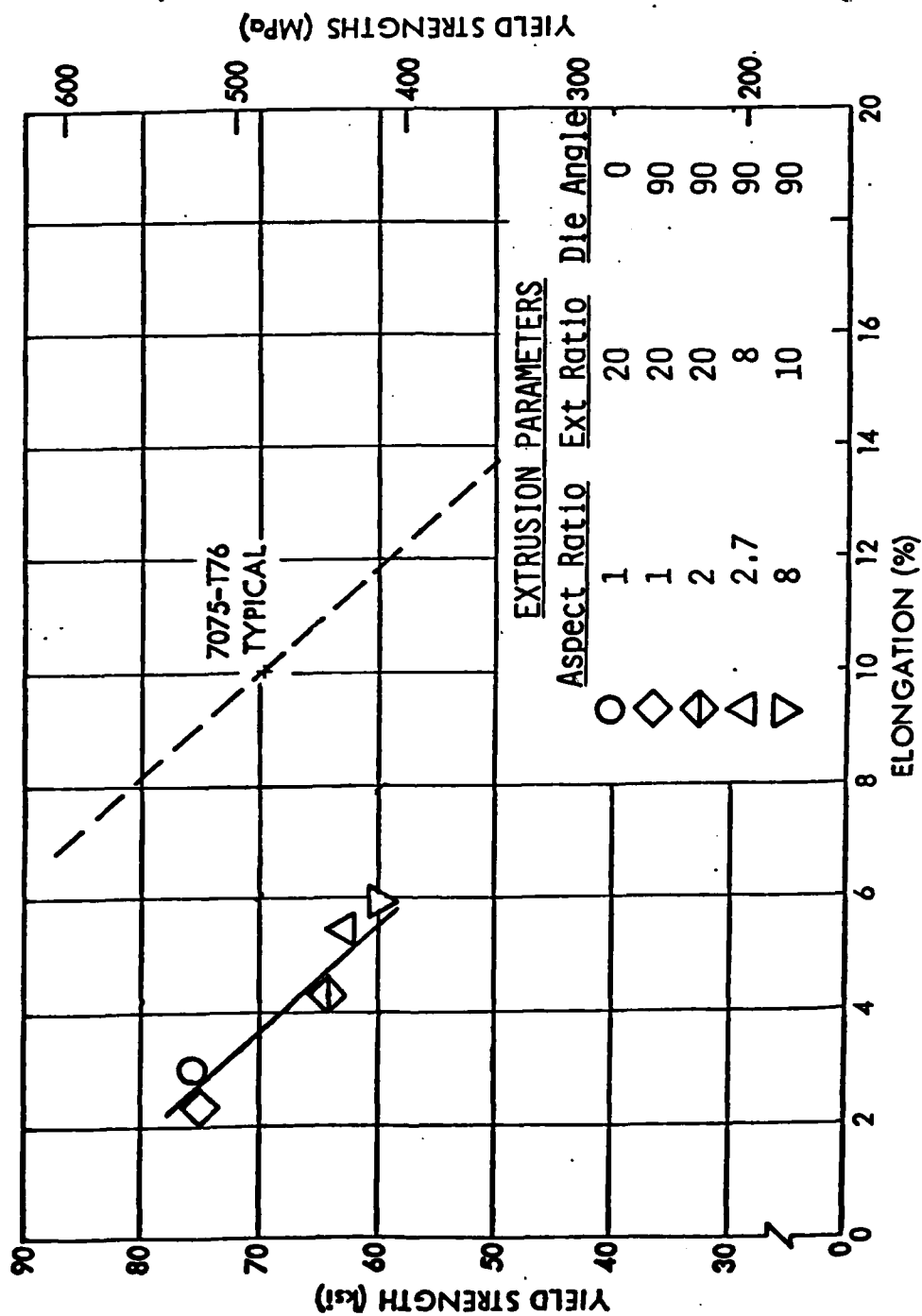


Fig. 1 Effect of Extrusion Aspect Ratio on Tensile Properties of Alloy 1.2
(Al-3Li-2Cu-0.2Zr) Peak Aged Condition

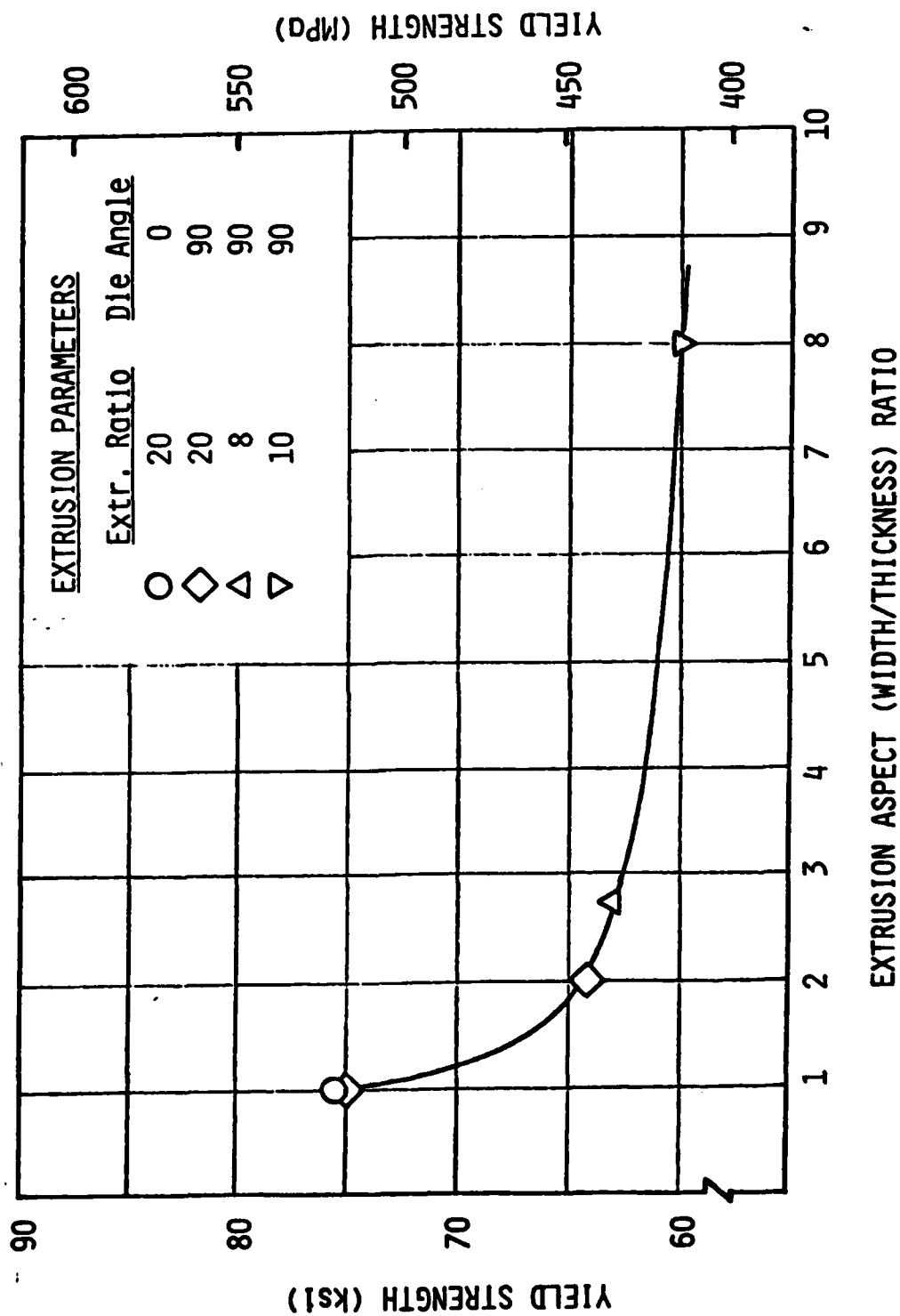


Fig. 2 Yield Strength as a function of Extrusion Aspect Ratio for Alloy 1.2 (Al-3Li-2Cu-0.2Zr), Peak Aged Condition